



Weapons of
Mass
Destruction

Heavy Water Production

Heavy water is the key to one type of reactor in which plutonium can be bred from natural uranium. As such, the production of heavy water has always been monitored, and the material is export controlled. In addition, a source of deuterium is essential for the production of tritium and ${}^6\text{LiD}$, two ingredients of thermonuclear weapons. A nation seeking large quantities of heavy water probably wishes to use the material to moderate a reactor, and may be planning to produce plutonium. However, CANDU (CANadian Deuterium Uranium) reactors designed and built in Canada are used for commercial electric power production.

Heavy water, D_2O , is water in which both hydrogen atoms have been replaced with deuterium, the isotope of hydrogen containing one proton and one neutron. It is present naturally in water, but in only small amounts, less than 1 part in 5,000. Heavy water is one of the two principal moderators which allow a nuclear reactor to operate with natural uranium as its fuel. The other moderator is reactor-grade graphite (graphite containing less than 5 ppm boron and with a density exceeding 1.50 gm/cm^3). The first nuclear reactor built in 1942 used graphite as the moderator; German efforts during World War II concentrated on using heavy water to moderate a reactor using natural uranium.

The importance of heavy water to a nuclear proliferator is that it provides one more route to produce plutonium for use in weapons, entirely bypassing uranium enrichment and all of the related technological infrastructure. In addition, heavy-water-moderated reactors can be used to make tritium.

Although one speaks of “making” heavy water, deuterium is not made in the process; rather, molecules of heavy water are separated from the vast quantity of water consisting of H_2O or HDO (singly deuterated water), and the “dross” is discarded. Alternatively, the water may be electrolyzed to make oxygen and hydrogen containing normal gas and

deuterium. The hydrogen can then be liquefied and distilled to separate the two species. Finally, the resulting deuterium is reacted with oxygen to form heavy water. No nuclear transformations occur.

The production of heavy water in significant amounts requires a technical infrastructure, but one which has similarities to ammonia production, alcohol distillation, and other common industrial processes. One may separate heavy water directly from natural water or first “enrich” the deuterium content in hydrogen gas. It is possible to take advantage of the different boiling points of heavy water (101.4 °C) and normal water (100 °C) or the difference in boiling points between deuterium (−249.7 °C) and hydrogen (−252.5 °C). However, because of the low abundance of deuterium, an enormous amount of water would have to be boiled to obtain useful amounts of deuterium. Because of the high heat of vaporization of water, this process would use enormous quantities of fuel or electricity. Practical facilities which exploit chemical differences use processes requiring much smaller amounts of energy. Separation methods include distillation of liquid hydrogen and various chemical exchange processes which exploit the differing affinities of deuterium and hydrogen for various compounds. These include the ammonia/hydrogen system, which uses potassium amide as the catalyst, and the hydrogen sulfide/water system (Girdler Sulfide process).

Separation factors per stage are significantly larger for deuterium enrichment than for uranium enrichment because of the larger relative mass difference. However, this is compensated for because the total enrichment needed is much greater. While ^{235}U is 0.72 percent of natural uranium, and must be enriched to 90 percent of the product, deuterium is only .015 percent of the hydrogen in water and must be enriched to greater than 99 percent. If the input stream has at least 5 percent heavy water, vacuum distillation is a preferred way to separate heavy from normal water.

This process is virtually identical to that used to distill brandy from wine. The principal visible difference is the use of a phosphor-bronze packing that has been chemically treated to improve wettability for the distillation column rather than a copper packing. Most organic liquids are non-polar and wet virtually any metal, while water, being a highly polar molecule with a high surface tension, wets very few metals. The process works best at low temperatures where water flows are small, so wetting the packing in the column is of particular importance. Phosphor-bronze is an alloy of copper with .02–.05 percent lead, .05–.15 percent iron, .5–.11 percent tin, and .01–.35 percent phosphorus.

Heavy water is produced in Argentina, Canada, India, and Norway. Presumably, all five declared nuclear weapons states can produce the material. The first commercial heavy water plant was the Norsk Hydro facility in Norway (built 1934, capacity 12 metric tons per year); this is the plant which was attacked by the Allies to deny heavy water to Germany. As stated above, the largest plant, is the Bruce Plant in Canada (1979; 700 metric tons/year). India’s apparent capacity is very high, but its program has been

troubled. Accidents and shutdowns have led to effective limitations on production.

The Bruce Heavy Water Plant in Ontario, Canada, is the world's largest producer of D²O. It uses the Girdler Sulfide (GS) process which incorporates a double cascade in each step. In the upper ("cold," 30–40 °C) section, deuterium from hydrogen sulfide preferentially migrates into water. In the lower ("hot," 120–140 °C) section, deuterium preferentially migrates from water into hydrogen sulfide. An appropriate cas-cade arrangement actually accomplishes enrichment. In the first stage the gas is enriched from 0.015% deuterium to 0.07%. The second column enriches this to 0.35% , and the third column achieves an enrichment between 10% and 30% deuterium. This product is sent to a distillation unit for finishing to 99.75% "reactor-grade" heavy water. Only about one-fifth of the deuterium in the plant feed water becomes heavy water product. The production of a single pound of heavy water requires 340,000 pounds of feed water.

Sources and Methods

- Adapted from - [Nuclear Weapons Technology](#) Militarily Critical Technologies List (MCTL) Part II: Weapons of Mass Destruction Technologies

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